

Pion Induced Reactions for the Study of Charmed Baryons

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In this talk, we report the study of $\pi^- p \rightarrow K^{*0} \Lambda$ and $\pi^- p \rightarrow D^{*-} \Lambda_c^+$ reactions by using an effective Lagrangian method and a hybrid Regge model. The total and differential cross sections for the $K^{*0} \Lambda$ production are first calculated and then those for the $D^{*-} \Lambda_c^+$ one are estimated. The two models yield different results, each exhibiting specific features. Our prediction for the charm production provides valuable information about the upcoming J-PARC experiment.

KEYWORDS: charmed baryons, effective Lagrangians, Regge model

1. Introduction

The production of open charmed mesons and baryons is now a major issue in hadron physics, as the electromagnetic- and hadron-beam energies increase enough to produce them at various experimental facilities. For example, there is a plan at J-PARC to conduct experiments to investigate the charmed baryons via the pion-induced reactions at a high-momentum beam line of up to 20 GeV/c [1]. The only previous work regarding this process $\pi^- p \rightarrow D^{*-} B_c$, where B_c denotes a charmed baryon in ground or excited states ($B_c = \Lambda_c^+, \Sigma_c^+, \dots$), was carried out almost thirty years ago [2] at BNL. However, none of signals for the charmed baryons was found but only an upper limit (95% confidence level) was estimated, namely, 7 nb at 13 GeV pion-beam energy. Thus it is of great importance to study the production mechanism of this reaction systematically.

On the theoretical side, the differential cross sections $d\sigma/dt$ for the strangeness and charm production, i.e. $\pi^- p \rightarrow K^{*0} \Lambda$ and $\pi^- p \rightarrow D^{*-} \Lambda_c^+$, have been computed with a simple Regge model [3], where vector-meson reggeon exchange was considered to provide a rough estimate of the relative strength. However, we want to elaborate the study of Ref. [3], employing both an effective Lagrangian method and a hybrid Regge model. We take into account the contribution of K (D) and Λ (Λ_c) reggeons as well as that of K^* (D^*) reggeon to the strangeness (charm) production. The Regge parameters are fixed by using the quark-gluon string model (QGS) done in Ref. [4].

2. Effective Lagrangians

We start with the strangeness production process $\pi^- p \rightarrow K^{*0} \Lambda$, for which the relevant tree-level Feynman diagrams are depicted in Fig. 1. We define the effective Lagrangians for each vertex by

$$\begin{aligned}\mathcal{L}_{\pi K K^*} &= -ig_{\pi K K^*}(\bar{K} \partial^\mu \tau \cdot \pi K_\mu^* - \bar{K}_\mu^* \partial^\mu \tau \cdot \pi K), \\ \mathcal{L}_{\pi K^* K^*} &= g_{\pi K^* K^*} \varepsilon^{\mu\nu\alpha\beta} \partial_\mu \bar{K}_\nu^* \tau \cdot \pi \partial_\alpha K_\beta^*,\end{aligned}\tag{1}$$

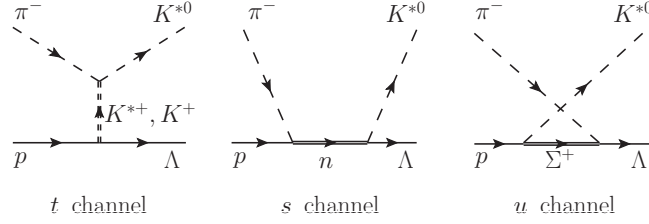


Fig. 1. Tree diagrams for the $\pi^- p \rightarrow K^{*0} \Lambda$ reaction.

for the meson-meson-meson interactions, and

$$\begin{aligned}
\mathcal{L}_{KN\Lambda} &= \frac{g_{KN\Lambda}}{M_N + M_\Lambda} \bar{N} \gamma_\mu \gamma_5 \Lambda \partial^\mu K + \text{H.c.}, \\
\mathcal{L}_{\pi NN} &= \frac{g_{\pi NN}}{2M_N} \bar{N} \gamma_\mu \gamma_5 \partial^\mu \tau \cdot \pi N, \\
\mathcal{L}_{\pi\Sigma\Lambda} &= \frac{g_{\pi\Sigma\Lambda}}{M_\Lambda + M_\Sigma} \bar{\Lambda} \gamma_\mu \gamma_5 \partial^\mu \pi \cdot \Sigma + \text{H.c.}, \\
\mathcal{L}_{K^*NY} &= -g_{K^*NY} \bar{N} \left[\gamma_\mu Y - \frac{\kappa_{K^*NY}}{M_N + M_Y} \sigma_{\mu\nu} Y \partial^\nu \right] K^{*\mu} + \text{H.c.}
\end{aligned} \tag{2}$$

for the meson-baryon-baryon interactions, Y being the Λ or Σ fields generically. The coupling constants are determined by using the experimental data for hadron decays, Nijmegen-potential, or SU(3) flavor symmetry. For more details, we refer to Ref. [5]. From the Lagrangians given above, we can construct the invariant amplitudes for each channel. Since the relevant hadrons have internal structures, the following form factor is introduced to each amplitude:

$$F_{ex}(p^2) = \frac{\Lambda^4}{\Lambda^4 + (p^2 - M_{ex}^2)^2}, \tag{3}$$

where p denotes the transfer momentum of the exchanged particle. To get the amplitudes for the charm process, $\pi^- p \rightarrow D^{*-} \Lambda_c^+$, we just replace the strange mesons and hyperons with charmed ones $K^+ \rightarrow \bar{D}^0$, $K^{*+} \rightarrow \bar{D}^{*0}$, $\Lambda \rightarrow \Lambda_c^+$, $\Sigma^+ \rightarrow \Sigma_c^{++}$. Regarding the cutoff masses, we choose the the same values for the t -channel and the s - and u - channels, respectively: $\Lambda_{K(D), K^*(D^*)} = 0.55$ GeV, $\Lambda_{N, \Sigma(\Sigma_c)} = 0.60$ GeV.

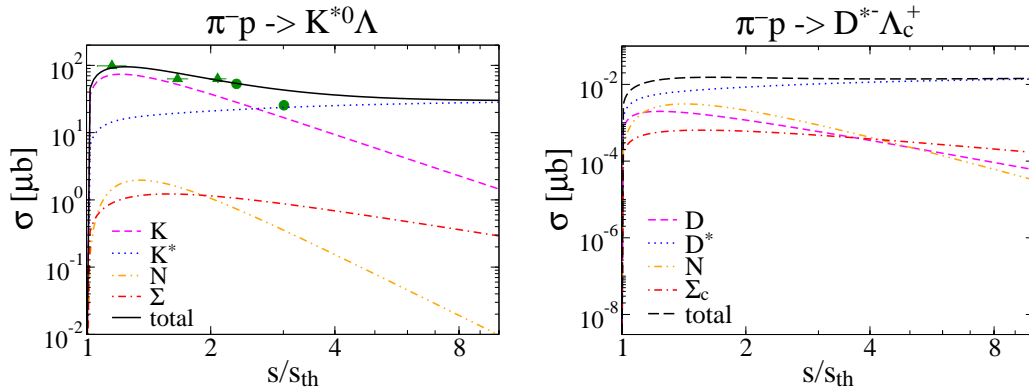


Fig. 2. Total cross sections for the $\pi^- p \rightarrow K^{*0} \Lambda$ (left panel) and $\pi^- p \rightarrow D^{*-} \Lambda_c^+$ (right panel) reactions based on the effective Lagrangian method. The data are from Ref. [6] (triangle) and from Ref. [7] (circle).

In Fig 2, the numerical results for the total cross sections are drawn as functions of s/s_{th} , where s_{th} is the threshold of s . In both reactions, we can find that the t -channel process gives the most dominant contribution to the total cross section. Especially, vector-meson exchanges play important roles in the high energy region.

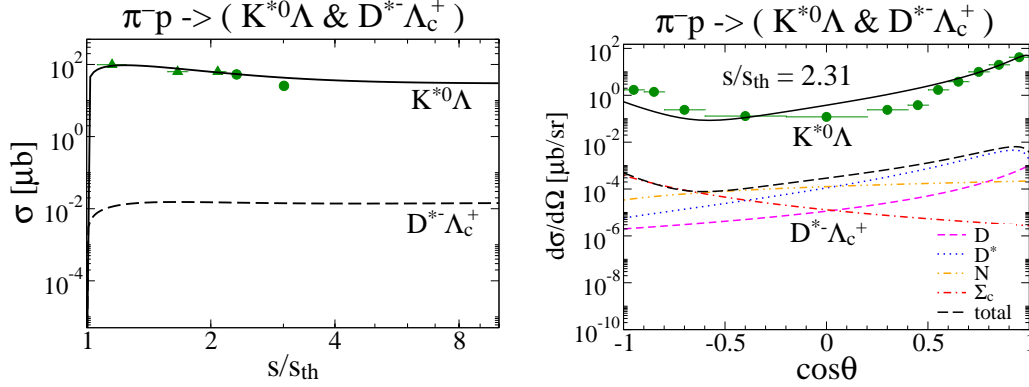


Fig. 3. Total (left panel) and differential (right panel) cross sections for the $\pi^- p \rightarrow K^{*0} \Lambda$ reaction in comparison with the $\pi^- p \rightarrow D^{*-} \Lambda_c^+$ one based on the effective Lagrangian method. The data are from Ref. [6] (triangle) and from Ref. [7] (circle).

Figure 3 describes the difference between the strangeness and charm production. It turns out that the cross sections for the charm production are approximately 10^4 times smaller than that for the strangeness one. Because of the large energy scale for the charm production compared to the strangeness one, the Feynman propagators and form factors are the main reason for this suppression.

3. Regge model

The Regge amplitudes are derived by replacing the Feynman propagator P^F with the Regge propagator P^R

$$P_{K^*}^F = \frac{1}{t - M_{K^*}^2} \Rightarrow P_{K^*}^R(s, t) = \left(\frac{s}{s_{K^*}} \right)^{\alpha_{K^*}(t)-1} \Gamma[1 - \alpha_{K^*}(t)] \alpha'_{K^*}, \quad (4)$$

for K^* reggeon exchange, for example. To extract the Regge trajectory $\alpha_{K^*}(t) = \alpha_{K^*}(0) + \alpha'_{K^*} t$ and scale parameter s_{K^*} , we rely on the quark-gluon string model (QGSM) [4]. The following form factor is considered to each amplitude:

$$F_{ex}(p^2) = \frac{a}{(1 - p^2/\Lambda^2)^2}. \quad (5)$$

The typical values are used for the cutoff masses $\Lambda = 1$ GeV in common. Other free parameters are chosen as $a_{K(D)} = 0.6$, $a_{K^*(D^*)} = 0.8$ and $a_{\Sigma(\Sigma_c)} = 1.5$ [5].

In Fig 4, each contribution to the total cross section is displayed. In both reactions, vector-meson reggeon exchange (K^* and D^*) governs its dependence on s over the whole energy region. The difference between pseudoscalar reggeon exchange and vector-meson reggeon one gets larger as s/s_{th} increases. The reason is obvious from the values of $\alpha(0)$ [4]. The contribution of baryon reggeon exchange (Σ and Σ_c) is almost negligible.

In Fig. 5, the difference between the strangeness and charm production is drawn. It is found that the cross sections for the charm production are about $10^4 - 10^6$ times smaller than that of the strangeness production depending on the energy range.

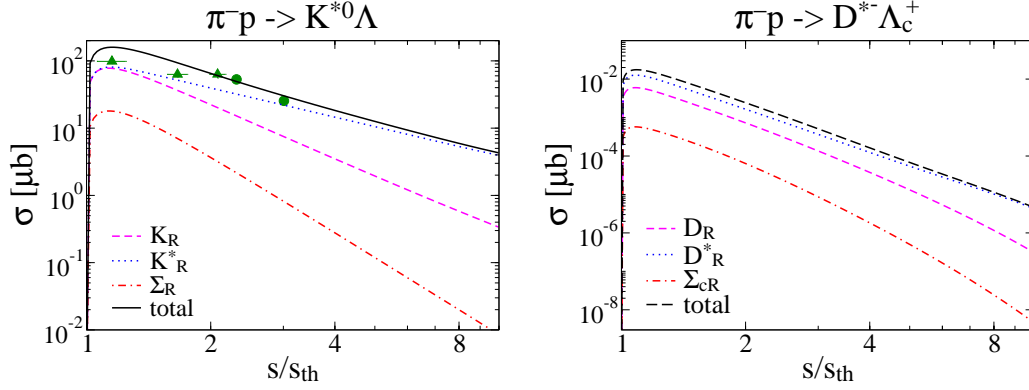


Fig. 4. Total cross sections for the $\pi^- p \rightarrow K^{*0} \Lambda$ (left panel) and $\pi^- p \rightarrow D^{*-} \Lambda_c^+$ (right panel) reactions based on the hybrid Regge model. The data are from Ref. [6] (triangle) and from Ref. [7] (circle).

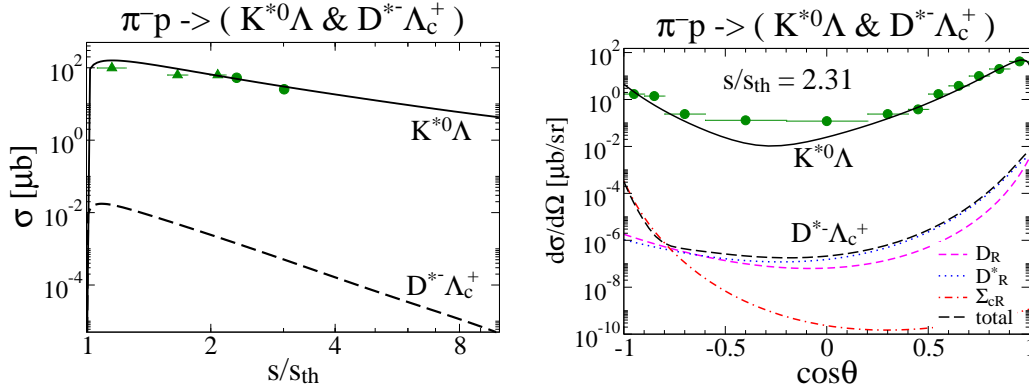


Fig. 5. Total (left panel) and differential (right panel) cross sections for the $\pi^- p \rightarrow K^{*0} \Lambda$ reaction in comparison with the $\pi^- p \rightarrow D^{*-} \Lambda_c^+$ one based on the hybrid Regge model. The data are from Ref. [6] (triangle) and from Ref. [7] (circle).

4. Summary

In the present talk, we investigated the pion-induced $K^{*0} \Lambda$ and $D^{*-} \Lambda_c^+$ production off the nucleon. In general, vector-meson (vector-meson reggeon) exchange turns out to be a dominant contribution in the effective Lagrangian method (Regge model). Our prediction of the charm production at $s/s_{th} \sim 2.1$, which is the expected maximum energy from the J-PARC facility [1], is suppressed by about factor 10^4 compared to the strange production. This indicates that the production cross section for the $D^{*-} \Lambda_c^+$ reaction is around 2 nb at that energy.

Acknowledgments

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